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PROVISIONAL SPECIFICATION

Invention Title: " A system and method for detecting specific substances using nuclear quadrupole resonance, and a coil used therewith"

The invention is described in the following statement:

"A system and method for detecting specific substances using nuclear quadrupole resonance, and a coil used therewith"

Field of the Invention

This invention relates to the detection of particular substances using nuclear and electronic resonance detection technology. It has particular application, with respect to nuclear quadrupole resonance (NQR), but some aspects of it also have application with respect to nuclear magnetic resonance (NMR), magnetic resonance imaging (MRI) and electron spin resonance (ESR) technologies.

One aspect of the invention more particularly relates to a practical system and method for detecting several substances simultaneously, which, for example in NQR terms, have NQR frequencies that can occur over a wide frequency range such as, 400 kHz and 5.5 MHz, or other NQR frequency ranges.

Another aspect of the invention also relates to a specific coil design that has utility with detecting substances using NQR, NMR, MRI and ESR technologies.

Within this document the term "substance" is taken to mean a material, which responds to a nuclear and electronic resonance phenomenon.

Throughout the specification, unless the context requires otherwise, the word "comprise" or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

Background Art

The following discussion of the background art is intended to facilitate an understanding of the present invention only. It should be appreciated that the discussion is not an acknowledgement or admission that any of the material referred to is or was part of the common general knowledge as at the priority date of the application.

Nuclear quadrupole resonance (NQR) is one of many modem research methods in physics used for the analytical detection of chemical substances in solid form. NQR is a radio frequency (RF) spectroscopy, and it is defined as a phenomenon of resonance RF absorption or emission of electromagnetic energy. It is due to the dependence of a portion of the energy of electron-nuclear interactions on the mutual orientations of asymmetrically distributed charges of the atomic nucleus and the atomic shell electrons as well as those charges that are outside the atomic radius. Thus, all changes in the quadrupole coupling constants and NQR frequencies are due to their electric origin.

The nuclear electric quadrupole moment eQ interacts with the electric field gradient eq, defined by asymmetry parameter η. Therefore the nuclear quadrupole coupling constant e^2Qq and the asymmetry parameter η, which contains structural information about a molecule, may be calculated from data obtained in respect of the emitted electromagnetic energy arising from absorbed RF electromagnetic energy in a substance having nuclei that exhibit the NQR phenomena.

The main spectral parameters of interest in testing for substances containing nuclei that exhibit NQR are the transition frequencies of the nucleus and the line width Δf thereof. Besides these parameter, obtaining spin-lattice relaxation time T_1, spin-spin relaxation time T_2 and line-shape parameter T_2^* (inversely proportional to Δf) are also of great value. These additional parameters must also be taken into consideration when choosing the technique and equipment for testing for the emission of NQR signals from a particular chemical substance.

In contrast to nuclear magnetic resonance (NMR) methods, NQR signal detection can be performed without a strong external DC magnetic field. This technique is known as "pure NQR", or direct NQR detection, and has many advantages over other techniques for certain applications, such as the identification of specific compounds and remote NQR detection. For example these methods are successfully used for detecting the presence of specific substances, such as explosives and narcotics, as well as landmine detection.

NQR can be detected in substances containing quadrupole nuclei with a spin quantum number greater than one half. The majority of widely used explosives and narcotics have such nuclei, among them being nitrogen (^{14}N), chlorine (^{35}Cl, ^{37}Cl), oxygen (^{17}O), sodium (^{23}Na), and potassium (^{39}K). The substance most frequently used for explosives and narcotics detection is nitrogen.

The probe of a pulsed NQR detection system is a device providing interaction between the RF field of an RF transmitter and a specimen that is targeted for the detection of an NQR signal from a substance therein, as well as the RF field response from the target specimen with a receiving part of the NQR detection system. Strong RF pulses, typically with the power of hundreds of watts are used. In practical NQR devices, when detecting specific substances (for example explosives and narcotics), the RF pulse power can reach several kW.

FIG. 1 illustrates a conventional prior art system for detecting NQR signals emitted from a targeted specimen. Transmitter unit **70'** and receiver unit **50'** are connected to probe **10'** through a duplexer and matching circuit **30'** which switches probe **10'** between the transmit and the receive mode. Transmitter unit **70'** generates RF pulses and applies the pulses to probe **10'** to excite the response from the substance. The pulses have a frequency corresponding to the resonance frequency of the nuclei of the substance. After the RF pulse is applied, probe **10'** can detect the emission of a response signal that may contain an NQR signal from a substance within the specimen, if present. The response signal is received by the receiver unit **50'** and processed by control and signal processing unit **90'** to detect the presence of an NQR signal and determine the type of substance that emitted the NQR signal. The control and signal processing unit **90'** also generates all control signals and the RF carrier for the transmitter unit **70'** to generate the RF signals that are applied to the probe **10'** and a reference RF signal for use by the receiver unit **50'**.

A practical system for the detection of specific substances must be able to detect at least several types of such substances. Each substance has its own NQR frequency, with the frequencies of different substances typically being within the range from 400 kHz to 5.5 MHz. For example RDX and HMX have NQR

frequencies around 5 MHz and 3 MHz, PETN – around 890 and 500 kHz, Black Powder – around 660 and 560 kHz, and ammonium nitrate – around 500 and 420 kHz. TNT has 12 frequencies within the range of 700 kHz to 900 kHz. Therefore an NQR detection system needs to operate over a wide frequency range.

One technique for measuring NQR substances using the prior art NQR detection system described above uses a resonant tank circuit made from a distributed RF coil sheet which is a single turn solenoid. Single turn solenoidal coils have been used in NMR. The advantages of such coils are the high homogeneity of the RF field and a high Q factor. Beyond these advantages, they have very low inductance, which is an attribute if the system is used for detecting substances at high frequencies. However when using such coils at low frequencies, in order to tune them to resonance, it is necessary to have a high value of capacitance, which presents considerable technical difficulties when connecting it into the circuit.

This is a particular problem for small or medium size coils circumscribing a target volume of up to several tens of litres. Such coils would typically find utility in NQR detection systems that could be used for the control of mail, mailbags or small baggage. As the coil inductance depends on the coil volume, smaller coils would have very low inductance. This would require very high capacitance to be added to the coil so that it can be resonant at the frequency of interest. For example, tuning a single turn solenoid coil with a volume of about 25 L to resonance of about 890 kHz in order to detect PETN based explosives requires approximately 430,000 pF of capacitance.

In most commercially viable types of NQR systems that have been developed to date, where explosives and narcotics are sought to be detected, only a single turn solenoid RF coil has been used, which has been intended to work at all frequencies. Shifting the resonant tank circuit from the frequency of one substance to the frequency of another substance is achieved by switching a series of fixed value capacitors by equal number of vacuum relays. For example, to retune a single turn solenoid coil with a volume of about 25 L from a frequency

of about 3.4 MHz for detecting RDX to a frequency of about 890 kHz for detecting PETN, it is necessary to switch approximately 400,000 pF of capacitance.

It has been discovered, pursuant to the present invention, that retuning the resonant tank circuit to a frequency that is several times lower by means of switching a large capacitance alone leads to a considerable decrease in the Q-factor of the resonant tank circuit. Furthermore, the switching elements that are used, such as vacuum relays, are a source of additional noise, including coherent noise or spurious signals.

A further problem in using the aforementioned type of NQR detection system utilising a single coil for the identification of several substances is that consecutive irradiation and analysis of the examined specimen needs to occur at different frequencies in a sequential manner. Consequently, when using this detection system for detecting a number of substances, or even a single substance, the detection process takes considerable time.

The same problem concerning the length of time taken to detect a number of substances, or a single substance, in items to be examined arises also with other nuclear and electronic resonance detection technologies such as NMR and ESR.

Disclosure of the Invention

The purpose of this invention is to provide a high probability of nuclear or electronic resonance signal detection in a relatively short detection time.

It is a preferred object of one aspect of this invention to provide high sensitivity of nuclear and electronic resonance signal detection in a wide frequency range and high detection characteristics in a plurality of specific frequency bands within that range.

It is a preferred object of another aspect of this invention to provide for an improved detection coil design.

In accordance with one aspect of the present invention, there is provided an apparatus for detecting a substance within items to be examined, comprising:

a plurality of discrete detection sub-units each dedicated to detecting a particular nuclear or electronic resonance signal within a specific frequency band;

each detection sub-unit having a detection coil adapted for tuning to a resonance frequency within the specific frequency band;

said detection coils being arranged so that examined items are input thereto from an incoming line of items and pass through the coils; and

said detection sub-units being operable to simultaneously detect a substance in said examined items using said detection coils according to the particular resonance frequency to which the detection coil thereof is tuned.

In one preferred arrangement, said substance and the particular resonance frequency are the same for each of the sub-units.

In an alternative preferred arrangement, said substance and the particular resonance frequency are different for each of the sub-units.

Preferably, in either preferred arrangement, the detection technology is NQR, NMR or ESR, or any combination of these.

Preferably a said detection coil comprises at least two turns and is arranged to ensure higher RF field homogeneity in the axial direction at the ends of the coil through an appropriate change of the turn width.

Preferably, the apparatus includes a conveyor system comprising a plurality of conveyor sub-units, corresponding to each of said detection sub-units for the purpose of conveying items to be examined into a target volume circumscribed by the corresponding detection coil of said detection sub-unit, each conveyor sub-unit working independently of the other, but having its operation synchronised so

that successive flow and optimum positioning of the examined items in the detection coils occurs.

In accordance with another aspect of the present invention, there is provided a method for detecting a substance using nuclear or electronic resonance from within items to be examined, the method comprising the following steps:

(a) inputting a first item to be examined into a target volume circumscribed by a first detection coil tuned to a resonance frequency;

(b) inputting a second item to be examined into a target volume circumscribed by a second detection coil tuned to a resonance frequency;

(c) simultaneously detecting the presence of any nuclear and electronic resonance signals in a specific frequency band corresponding to said resonance frequency being detected by the particular coil; and

(d) exiting the examined items from said detection coils; and

(e) repeating steps (a) to (d) with the next items to be examined.

Preferably, the nuclear or electronic resonance is NQR, NMR or ESR, or any combination of these, whereby a detection coil is dedicated to detecting said resonance using a particular detection technology.

In one preferred arrangement, the resonance frequency and the substance being detected are the same for each of the detection coils.

In an alternative preferred arrangement, the resonance frequency and the substance being detected are different for each of the detection coils.

In the alternative preferred arrangement, preferably, the method comprises:

(a) detecting the presence of any NQR signals in the first detection coil in a specific frequency band corresponding to said first resonance frequency immediately after locating the first item into the target volume of the first detection coil;

(b) transporting the first examined item into the target volume of the second detection coil the second detection coil being tuned to a second resonance frequency different from the first resonance frequency, while at the same time transporting a second item to be examined to the target volume of the first detection coil;

(c) simultaneously detecting the presence of any nuclear or electronic resonance signals in both coils;

(d) exiting the first examined item from the second detection coil and simultaneously transporting the second examined item into the target volume of the second detection coil, while at the same time transporting a third item to be examined to the target volume of the first coil;

(e) simultaneously detecting the presence of any nuclear or electronic resonance signals in both coils; and

(f) repeating the process successively from step (b) to (e) with successive items to be examined, until all items desired to be examined for the presence of particular substances having nuclear or electronic resonance signals corresponding to the resonance frequencies of said detection coils have been examined for the presence of such signals.

In accordance with a further aspect of the invention, there is provided a ribbon width detection coil for a probe of an apparatus adapted for detecting NQR signals of a targeted substance from within an item examined for such, the coil comprising:

a pair of turns, one part of each turn being much wider than the other part;

said turns being arranged in an inverse manner to circumscribe a target volume with open ends, whereby:

(i) said one part of each turn is situated at an end and at a side of the coil, and said other part of each turn is situated at an opposing end and opposing side of the coil;

(ii) said other part of one turn being disposed at one end and at one side of the coil, and said other part of the other turn being disposed at the opposite end and opposite side of the coil;

(iii) said one part of said one turn being disposed to extend to the opposite end and at the opposite side of the coil to said other part of the same turn, and said one part of said other turn being disposed to extend to the opposite end at the opposite side of the coil to said other part of the same turn; and

(iv) neither turn having contact with the other at its edges; and

(v) said turns being marginally spaced apart to define a longitudinal gap therebetween.

In this coil arrangement, a multiplicity of capacitors may be placed between the wider one parts of the turns of the coil, across and along the gap to enable selective tuning over a range of frequencies.

In accordance with a further aspect of the present invention, there is provided an apparatus for detecting NQR signals for a plurality of substances within items to be examined, comprising:

a plurality of discrete detection sub-units each dedicated to detecting an NQR signal within a specific frequency band, whereby said specific frequency bands are disposed in different regions of a wide frequency range;

each detection sub-unit having a detection coil adapted for tuning to a resonance frequency within a specific frequency band for detection of a specific substance during a prescribed time period;

said detection coils being arranged in a circular fashion about a central axis wherein an item to be examined is conveyed into a target volume of a coil disposed adjacent an entry point, and is discharged from the target volume of a coil disposed at an exit point; and

said detection sub-units being operable to simultaneously detect different or the same substances using said detection coils according to the particular resonance frequency to which the detection coil thereof is tuned, within different coils or at different relative locations about the central axis.

Preferably, said coils are fixedly disposed with respect to said central axis, and said items are conveyed consecutively through the coils from the entry point to the exit point, the items being disposed within the target volume of each coil for discrete NQR processing independently of each other for detection of a specific substance to which the particular coil thereof is tuned.

Alternatively, said coils may be rotatedly disposed with respect to said central axis, said items being conveyed into a target volume of a coil when the coil is disposed at an entry station at said entry point, and discharged from the target volume of the coil when the coil is disposed at an exit station at said exit point, the detection sub-unit of each coil being adapted to cycle through a series of NQR processing routines for detecting a plurality of different specific substances, independently of, and in parallel with, the other coils, whilst an item is disposed within the target volume thereof during the passage of each coil from the entry station to the exit station, so that the detection process is completed for all substances being detected for an examined item by the time that the coil reaches the exit station.

Brief Description of the Drawings

FIG. 1 (prior art) is a block diagram of a conventional apparatus for detecting an NQR signal in a specimen.

FIG. 2 is a block diagram illustrating an apparatus for detecting an NQR signal in a specimen, according to a first embodiment of the present invention.

FIG. 3 is a flow diagram illustrating a method for detecting a resonance signal in the specimen and a practical system of operation of the apparatus of the first embodiment.

FIG. 4 shows the coil used in the apparatus of the first embodiment.

FIG. 5 shows the circuit diagram of the tank circuit used in the apparatus of the first embodiment.

FIG.6 shows calculated magnetic field amplitude profiles, normalised to the field amplitude B_m in the centre of a detection coil, along the central axis of the coil, wherein:

> FIG 6A shows the profile for a single turn solenoid (distributed RF coil sheet); and
>
> FIG. 6B shows the profile for a double turn coil with a variable ribbon width, according to the first embodiment described in relation to the present invention.

FIG.7 shows a top view diagram of a carousel type NQR scanner with three coils in accordance with a second embodiment of the invention.

FIG.8 shows a top view diagram of another carousel type NQR scanner in accordance with a third embodiment of the invention.

FIG.9 is a diagrammatical block diagram showing an arrangement using NQR, NMR and ESR detection technologies for the detection sub-units, in accordance with the fifth embodiment.

FIG.10 is a block diagram similar to FIG.2, but in accordance with the fourth embodiment.

Best Mode(s) for Carrying Out the Invention

The best mode for carrying out the invention will now be described in the following specific embodiments. The description is made with reference to figures 2 to 8 of the accompanying drawings.

The first embodiment is directed towards a scanning system and method using NQR for detecting the presence of a plurality of substances that may be present within items to be examined within a target volume.

As shown in FIG. 2, the system comprises two probes **10, 20** that form part of two discrete detection sub-units. One of the detection sub-units incorporating probe **10** is designed to operate in the high frequency band, normally above 1 MHz, and the other sub-unit incorporating detection probe **20** is designed to operate in the low frequency band, normally below 1 MHz.

In the higher frequency detection sub-unit, probe **10** is connected to receiver unit **50** and conventional transmitter unit **70** via duplexer and matching circuit **30**. In the lower frequency detection sub-unit, probe **20** is connected to receiver unit **60** and conventional transmitter unit **80** via duplexer and matching circuit **40** accordingly.

Probe **10** includes detection coil **1**, being a high frequency coil **1**, fixed capacitor **3** and tune circuit **5**. Probe **20** includes detection coil **2**, being a low frequency coil **2**, fixed capacitor **4** and tune circuit **6**. Probes **10** and **20** are tuned to the frequencies of interest corresponding to the NQR resonance frequencies of each substance to be detected.

The probes each have a shield (not shown) associated therewith to shield the coils thereof from the influence of external noise. The shield also functions to isolate electromagnetic radiation generated by the probe thereof from the surrounding environment.

The duplexer and matching circuit **30** of the high frequency detection sub-unit switches probe **10** between the transmit and receive modes as well as matching the receiver unit **50** and transmitter unit **70** to probe **10**. Similarly, the duplexer and matching circuit **40** of the low frequency detection sub-unit switches probe **20** between the transmit and receive modes as well as matching the receiver unit **60** and transmitter unit **80** to probe **20**. Transmitter units **70** and **80** generate RF pulses and transfer the pulses to probe **10** and **20** accordingly.

These RF pulses can excite NQR signals in the item under investigation, upon the item being located with the target volume of the detection coils, which are located in probes **10** and **20**. The signals received in response to irradiation of the item with the RF pulses by the transmitter units **70** and **80** are amplified and detected by receiver units **50** and **60** and are then delivered for further mathematical processing into the common control and signal processing unit **90** via inputs that are connected with the outputs of receiver units **50** and **60**.

To move the items, a conveyor sub-system **100** comprising conveyor sub-units **130** and **140** is used. Belts of conveyor sub-units **130** and **140** are arranged to move an item to be examined inside each of the coils **1** and **2**, accordingly. Conveyor sub-units **130** and **140** are independent conveyors and each of them is controlled by its own control unit-1 **110** and control unit-2 **120**, accordingly. Each of conveyor sub-units **130** and **140** comprises means for exact positioning of an item to be examined in the centre of the detection coil corresponding therewith. Conveyor sub-units **130** and **140** together with their respective coils **1** and **2** are placed sequentially so that an item examined in coil **1** can then proceed to coil **2**.

The control and signal processing unit **90** in the present embodiment generates two RF signals, one for each detection sub-unit. These RF signals are split for each detection sub-unit, so that they are transmitted from one set of outputs to one of the inputs of the respective transmitter units **70** and **80**, and from another

set of outputs to one of the inputs of the respective receiver units **50** and **60**. In the case of the transmitter units **70** and **80** they are used for further formation of the RF carrier of the RF pulses, and in the case of the receiver units **50** and **60**, they are used as the reference frequency.

The control and signal processing unit **90** also generates tuning control signals, which are transferred to the inputs of tune circuit **5** and tune circuit **6** for tuning probes **10** and **20** of the detection sub-units at respective resonant frequencies.

Furthermore, the control and signal processing unit **90** generates conveyor control signals, which are transferred to control unit-1 **110** and control unit-2 **120** for controlling conveyor sub-units **130** and **140**.

The control and signal processing unit **90** also generates pulse formation control signals, which are transferred to other inputs of transmitter units **70** and **80** and prescribe parameters for RF pulses.

The control and signal processing unit **90** in the present embodiment consists of a computer, an RF signal source and electronic circuits (for producing control signals), which are not specific for the present invention and are not described here in any detail.

Besides its specifically determined NQR frequency, each target substance also has characteristic relaxation parameters. This means that for the optimum detection of each target substance it is desirable to use an optimum pulse sequence. Such pulse sequence is determined for each target substance beforehand and entered into the memory of the control and signal processing unit **90** for later use in the detection procedure.

Similarly, parameters for the type of signal processing to be performed for each target substance are entered into the memory of the control and signal processing unit **90** and are also later used in the process of detection.

FIG. 3 is a flow diagram illustrating the methodology of operation followed by the NQR system of the present embodiment for detecting the resonance signal in the

target substances. The process starts in step S100 by placing the first item to be examined in the target volume of the first coil, which in the present embodiment is the high frequency coil.

From step S100, the process moves to step S110, which involves the complete NQR signal detection process in the first item located in the first coil. This process includes applying the RF excitation at the NQR frequency to the item, receiving the response signal from the item, and signal processing.

From step S110, the process moves to step S120, which involves moving the item from the first coil to the target volume of the second coil, which in the present embodiment is the low frequency coil.

If at least one more item on the conveyor belt of the conveyor sub-system is in line to be examined in the first coil, the process moves to step S130 which involves bringing this next item into the first coil. If the last item in the queue was moved from the first coil to the second coil during step S120, the process moves to step S160. In the latter case, a full detection process for detecting the presence of any NQR signal corresponding to the target substance sought to be detected, emanating from the item located in the second coil only, is performed. This process consists of applying the RF excitation at the NQR frequency to the sample, receiving the response signal from the sample and signal processing.

In the former case, from step S130, the process moves to step S140, which involves a complete NQR signal detection process in the items located in both coils. The process also includes applying the RF excitation at the NQR frequencies to the both items via the respective detection sub-units, receiving the response signals from the items, and signal processing, in their proper sequence, but in a concurrent manner between the two detection sub-units.

From step S140, the process moves to step S150, where the item exits the second coil. From step S150, the process moves back to step S120.

In the case when there are no further items to be examined, from step S160, the process moves to step S170, where the last item is finally moved out of the second coil.

The purpose of the features of the apparatus shown in FIG.2, when applied to the process described in conjunction with the flow chart shown in FIG.3, allows for the following steps:

(a) Conveyor sub-unit **130**, which is controlled by control unit-1 **110**, places the item in the coil **1** of the probe **10**.

(b) Transmitter unit **70** generates RF pulses at the frequency corresponding to one of the NQR frequencies and provides the pulses via duplexer and matching circuit **30** to probe **10**. After the recovery period the signal from the output of probe **10** is transmitted to the input of receiver unit **50**. Signals transmitted to receiver unit **50** are amplified, detected and sent for further mathematical processing to control and signal processing unit **90**.

(c) Conveyor sub-unit **130**, which is controlled by control unit-1 **110**, replaces the item from coil **1** and places the next item in coil **1** of probe **10**. Conveyor sub-unit **140**, which is controlled by control unit-2 **120**, places the item in coil **2** of probe **20**.

(d) Transmitter unit **70** generates RF pulses on the frequency corresponding to one of the NQR frequencies and provides the pulses via duplexer and matching circuit **30** to probe **10**. At the same time transmitter unit **80** generates RF pulses at the frequency corresponding to one of the NQR frequencies and provides the pulses via duplexer and matching circuit **40** to probe **20**. After the recovery period the signals from the output of probe **10** and probe **20** are transmitted to the input of receiver unit **50** and receiver unit **60** respectively. Signals transmitted to receiver unit **50** and receiver unit **60** are amplified, detected and sent for further mathematical processing to control and signal processing unit **90**.

(e) Conveyor sub-unit **140** controlled by control unit-2 **120** replaces the item from coil **2** of probe **20**.

(f) After that, if at least one item was left unexamined in the first coil, the process moves back to step (c). If the last item was placed in the first coil conveyor sub-unit **130** controlled by control unit-1 **110** replaces the item from coil **1** and conveyor sub-unit **140** controlled by control unit-2 **120** places the item in coil **2** of probe **20**.

(g) Transmitter unit **80** generates RF pulses at the frequency corresponding to one of the NQR frequencies and provides the pulses via duplexer and matching circuit **40** to probe **20**. After the recovery period the signal from the output of probe **20** is transmitted to the input of receiver unit **60**. Signals transmitted to receiver unit **60** are amplified, detected and sent for further mathematical processing to control and signal processing unit **90**.

(h) Conveyor sub-unit **140** controlled by control unit-2 **120** moves the item out of coil **2** of probe **20**.

As one can see in FIG. 2, at least two probes are used in the present invention, each of them is designed to operate over a strictly defined frequency range. The parameters of the coil, capacitance and tune circuit for each probe are chosen so that they correspond to the specific frequency range of the particular substance to be targeted. The duplexer and matching circuits, receiver units and transmitter units used in the detection system are also designed to operate over the same specific frequency range. Such a design permits considerable simplification of the tuning circuits, and excludes the possible sources of additional noise and improves the signal to noise ratio (SNR). The existence of several (at least two) independent probes and conveyor sub-units permits simultaneous detection of the NQR signals in several items at different frequencies. When checking a large number of items for target substances this gives a considerable gain in the detection time, which is important for time constrained detection such as in airport scanning.

The specific configuration for each of the detection coils **1** and **2** used in the present embodiment is quite special, whereby each coil has a varying ribbon width made of a material of high electrical conductivity (ribbon copper, for example).

As shown in FIG.4, coil **1** is particularly formed having two turns **7** and **8**, with one half of each turn being much wider than the other half. The turns are particularly arranged in an inverse manner so that the part of the turn having the smaller width is situated at an end and a side of the coil, the smaller part of one turn at one end and one side of the coil, and the smaller part of the other turn at the opposite end and opposite side of the coil. The part of each turn having the larger width is arranged in either case to constitute the central and main area of the coil, at the opposite end and opposite side of the other part of the same turn, as shown. Neither turn of the coil has direct contact at its edges with the other turn, and the turns themselves are marginally spaced apart to define a longitudinal gap **9**.

A multiplicity of fixed value capacitors **11** (and/or variable value capacitors in other embodiments) are connected between the wide ends of the turns and are located along gap **9**.

A circuit diagram illustrating the preferred method of connecting the coil in the tank circuit according to the present embodiment is shown in FIG.5. As can be seen in this method, the coil is connected to provide a balanced circuit. This helps to reduce the electric losses in the sample and also reduce the radiative and resistive losses in the ground loops.

The double turn coil shown in FIG. 4 not only preserves the uniformity of the RF field in the central area of the target volume circumscribed thereby, typical for a single turn solenoidal coil, but also increases the uniformity of the RF field at the edges of the coil. Furthermore, this double turn coil has a greater inductance as compared with a single turn solenoidal coil of the same dimensions, which makes it more suitable for use in a low-frequency range as well as for the detection of target substances in small or medium volumes.

FIG. 6 shows calculated magnetic field amplitude profiles, normalised to the field amplitude B_m in the centre of the coil, along an axis parallel to the coil axis. FIG. 6(a) shows the profile for a single turn solenoid (distributed RF coil sheet) according to the prior art. FIG. 6(b) on the other hand shows the profile for the double turn coil with a variable ribbon width, according to the present embodiment of the invention. It can be easily observed from these figures that in the case of

the double turn coil with a variable ribbon width the uniformity of the magnetic field is almost three times higher as compared with a prior art single turn solenoid (distributed RF coil sheet).

The second embodiment is substantially the same as the first, except that the coils are physically arranged in a circular fashion to form a carousel arrangement as shown in FIG.7.

In this arrangement, the carousel NQR apparatus **250** has three coils **200**, **201**, **202** disposed about a central axis **207** and interconnected by a circular conveyor sub-system **208**. The detection sub-units are logically associated in a corresponding manner with the coils, although it should be appreciated that those components of the sub-units concerned with processing functions would be collectively located in a common control area associated with the apparatus for convenience. For example, all components other than the probes would be located in a common control box, together with the control and signal processing unit.

The NQR apparatus **250** has an entry point **203** to the conveyor belt of the conveyor sub-system **208**, where a piece of luggage to be scanned is dropped from above into the carousel. The apparatus also has an exit point **204**, where the luggage exits the carousel, falling below the carousel to be transported by another conveyor to its next destination.

From the entry point **203** to the exit point **204**, the bag is successively transported via the conveyor belt of the conveyor sub-system, through the coils **200**, **201**, and **202** being scanned for different quadrupolar substances at each coil.

The NQR apparatus **250** is provided with an external electromagnetic shield **206** that shields the coils **200**, **201**, and **202** from external RF interferences.

This carousel arrangement has the advantage of reducing the length of the NQR apparatus at the expense of the width and height of the apparatus. The removal of waveguides from either end of the shield, also reduces the length of the apparatus. By enabling the bag to fall in from above and fall out of the apparatus

further length is saved by using the vertical dimension to advantage. The length reduction is important because of the limited space available in typical airports.

The use of the three coils enables three different frequencies to be scanned separately, which means that the coils can be used simultaneously to increase the throughput by a factor of 3 over conventional single coil systems. Each coil can be tuned to a particular frequency, thus eliminating the need to switch tuning capacitors between widely different frequencies. The use of fixed capacitors allows a high Q to be maintained for the system across all detection frequencies by avoiding the use of a switch.

The three coils in FIG.7 also have their longitudinal axis angularly disposed transversely with respect to the adjacent coil, to minimise interference from each coil affecting the next coil. As shown, coil **201** is orthogonally disposed with respect to adjacent coils **200** and **202**. If the coils were aligned end on end interference would be a much greater problem..

The third embodiment is substantially the same as the first and similar to the second embodiment in that the NQR system is in the form of a carousel arrangement with the coils disposed in a circular fashion. In this embodiment, however, the coils are rotatable about a central axis to cycle through a series of NQR processing routines for detecting a plurality of different specific substances in an examined item, independently of and in parallel with each other concurrently, as the coils pass through different locations around the central axis.

As shown in FIG.8, the NQR apparatus **260** comprises a common shield **218** as before, but this shield is provided with an entry waveguide **214** and an exit waveguide **213** associated with an entry conveyor **216** and an exit conveyer **215**. The shield **218**, as before, provides shielding from external interference and the conveyors respectively deliver baggage to be examined to the apparatus and discharge baggage from the conveyor that has finished being examined. The apparatus also includes a plurality of coils, but instead of being fixed as before with the conveyor transporting items therebetween, the coils themselves are rotatable upon a carousel, about a central axis **220**. In the arrangement shown in FIG.8, the coils at different times are arranged to be located at a loading station

210, an intermediate station **211** and an exiting station **212**. Accordingly, the waveguides **213, 214** are cut an angle **217** to enable the three coils to slide past the waveguides without contact.

Describing the operation of the apparatus in the particular configuration shown in FIG.8 at a particular point in time, a bag **219** is transported into the entry waveguide **214** by the conveyor belt **216** where it eventually reaches a coil located at the entry station **210**. Once the bag **219** is located within the target volume of the coil at the entry station **210**, the bag is scanned for the first NQR substance. After the scan has been completed, the coil is rotated in the carousel to the intermediate station **211**. The coil that was originally located at the exiting station **212** moves to the loading station **210** and another bag is moved via the conveyor belt **216** and entry waveguide **214** into the coil and scanned. Whilst this is in progress the original bag **219** which is now at the intermediate station **211** is scanned for the second substance. The process continues within the original bag eventually being rotated to the exiting station **212** where the final scan is completed. On completion, the bag **219** exits the coil and is transported by conveyor belt **215** through the second waveguide **214** and out of the apparatus to its next destination.

Whilst the bags/coils are in transit between positions it is possible to scan or tune the coil system, i.e. it is not necessary to wait until the coil has stopped moving. The net result of this is that the throughput and efficiency is greater than what could be achieved with a single coil on its own, by a factor of 3.

The use of the carousel arrangement of the present embodiment, although requiring the coil of the one probe to be switched to detect different substances at different resonance frequencies, nonetheless enables the construction of a more compact NQR scanning apparatus, on the basis of economies of scale, and achieve greater throughput than if the coils were simply placed end on end or if a single coil system was to be used.

The fourth embodiment is substantially the same as the first, except that the sub-units are both tuned to the same or very similar frequencies. This provides the

advantage of achieving twice the scan rate as is the case with using a single sub-unit alone.

As shown in Figure 10, the same reference numerals have been adopted for indicating the various components of the apparatus, as used in the first embodiment, except that they have been annotated with ".

In this embodiment, an item to be scanned is passed through the first coil 1" and into the second coil 2", without being scanned in the first coil. The second item in the queue passes into the first coil 1" and the two scan items are scanned simultaneously in the two coils.

After scanning has been completed, the two items that were scanned are transferred out of the target volumes of the coil for subsequent action, and the next two items in the queue are brought into position for scanning within the target volumes, as in the case of the former two items. These items are then simultaneously scanned, and transferred out of the target volumes for discharge.

This process is repeated for subsequent items in the queue.

Adopting this method of detection results in a scan rate that is twice that which can be achieved by a single coil detection system or one that comprises a single detection sub-unit. This is important because generally, NQR scanners are slower than high speed X-ray scanners. Accordingly, in situations where it may be necessary for an NQR scanner to work in tandem with an X-ray scanner, two or more NQR scanners with dual detection sub-units of the type described in the present embodiment, may be placed sequentially in advance of, or behind an X-ray scanner, so that the NQR scanner(s) may keep pace with the X-ray scanner.

The fifth embodiment is substantially the same as the first embodiment, except that one or both of the two detection sub-units are of another type of scanner than an NQR type.

In one arrangement, one of the detection sub-units is an NMR explosive detector scanner type, and the other is of an NQR type.

Such a detection system would enable materials that are difficult to be detected by NQR, such as TNT, to be scanned by the NMR detection sub-unit, and materials that are more easily detected by NQR, such as RDX, HMX and PETN, to be scanned by the NQR detection sub-unit. This would enable the entire apparatus to achieve a greater detection capability than just by using NQR detection sub-units alone.

In a further arrangement of this embodiment, expanding upon the aforementioned arrangement, a further detection sub-unit is provided, in addition to the NMR and NQR detection sub-units, which is of a different type of scanner than both NMR and NQR, in the present embodiment being an ESR detection sub-unit.

As shown diagrammatically in Figure 9, the detection system comprises an NMR detection sub-unit **500**, followed by an NQR detection sub-unit **501**, which is in turn followed by an ESR detection sub-unit **502**.

ESR has the advantage, at present, of being able to detect black powder more easily than other detection technologies, such as NMR and NQR. Consequently, in this further arrangement, the detection capability of the complete apparatus would be extended further, than in the previous embodiments or the previous arrangement of the present embodiment, by being able to detect black powder. In implementing either of the arrangements of the present embodiment, the circuitry for both the NMR and ESR sub-units is similar to the circuitry shown in FIG. 2, except that both of these technologies will require a large DC magnet (not shown), and operation methodology to suit the particular technology to which the detection sub-unit is implementing. As this circuitry is commonly known in the fields of NMR and NQR design, it will not be described in detail here.

The sixth embodiment is substantially similar to the fourth embodiment, wherein both detection sub-units are of the same type of detection technology, however in the present embodiment, the detection technology is not NQR.

In one arrangement of the embodiment, the detection technology is NMR, and in an alternative arrangement, the detection technology is ESR.

In both of these arrangements, throughput is increased in multiply by the number of sub-units added in sequence, for the particular technology being utilised.

As can be seen from the above, the preceding embodiments and arrangements cover a variety of embodiments in which the best mode for carrying out the invention may be implemented. In this sense, the invention in its broadest form can be applied to a number of different detection technologies.

In its simplest form according to one aspect of the invention, the best mode for carrying out the invention is achieved by placing two or more detection sub-units adjacent to each other to form a single scanning apparatus, but with multiple probes and ancillary circuitry constituting a detection sub-unit.

In its simplest form according to another aspect of the invention, the best mode for carrying out the invention is achieved using a double turn coil in the probe of the detection sub-units.

Each sub-unit can be tuned to the same frequency, i.e. to measure the same substance, or differing frequencies or utilising differing detection technology, i.e. to measure different substances, as desired. However, the optimal arrangement involves the use of at least two probes, designed to work in different frequency ranges, a conveyor system comprising at least two independent sub-units and coils with a variable ribbon width.

Such an arrangement in combination provides for a scanning and detection system that permits a marked increase in the efficiency of detecting target substances than provided by conventional prior art designs.

It should be appreciated that the scope of the present invention is not limited to any one of the specific embodiments herein described. In particular, modifications or improvements may be made to certain components or features described in any of the embodiments, in accordance with good engineering practice, without departing from neither the spirit nor scope of the present invention.

Dated this Ninth day of June 2003.

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Wray & Associates
Perth, Western Australia
Patent Attorneys for the Applicant(s)

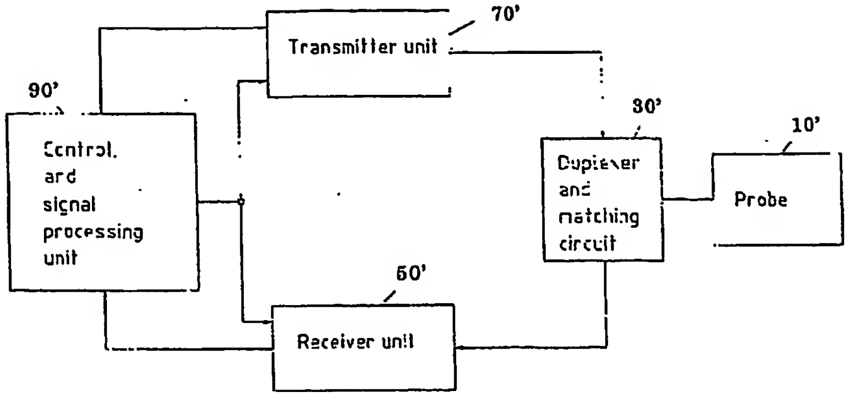


Fig. 1 Prior art

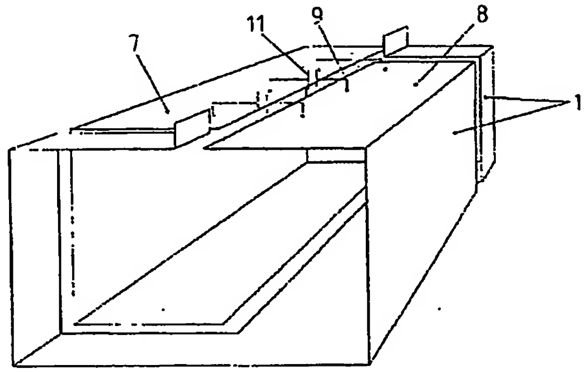


Fig. 4

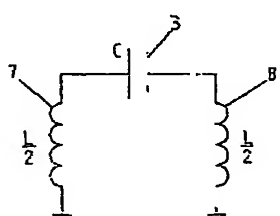
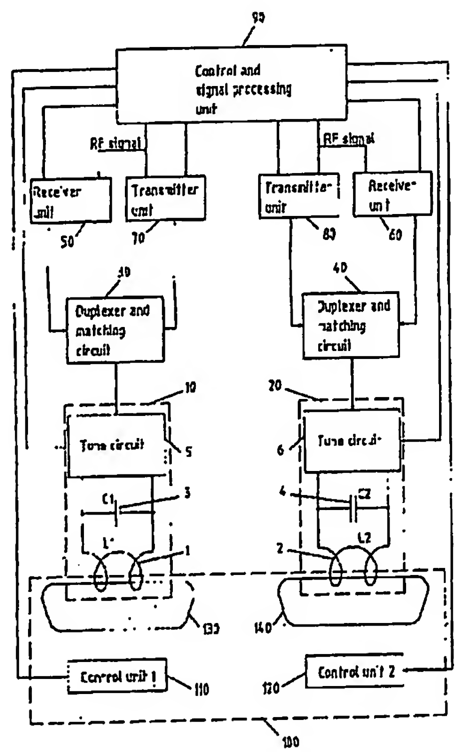
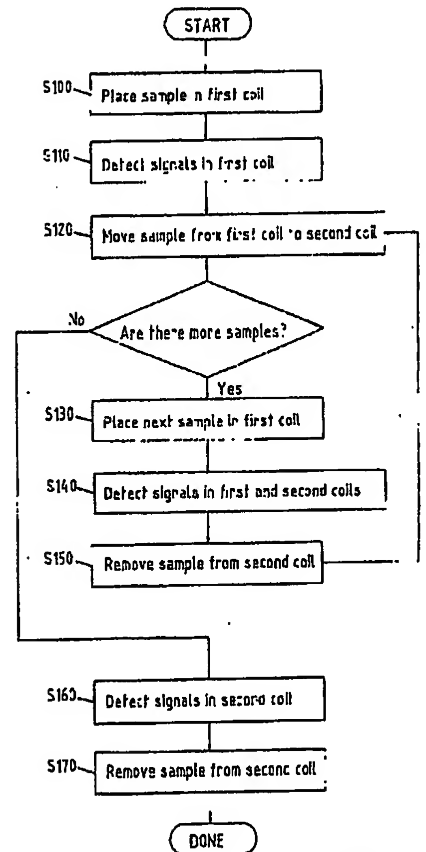


Fig. 5



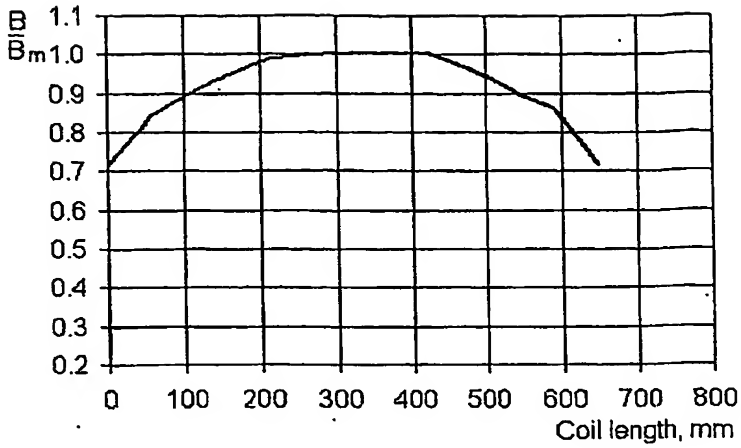
Control and signal processing unit
90
RF signal
RF signal
Receiver unit
Transmitter unit
Transmitter unit
Receiver unit
50
70
80
60
30
40
Duplexer and matching circuit
Duplexer and matching circuit
10
20
Tune circuit
Tune circuit
5
6
C1
C2
3
4
L1
L2
1
2
130
140
Control unit 1
Control unit 2
110
120
100

Fig. 2



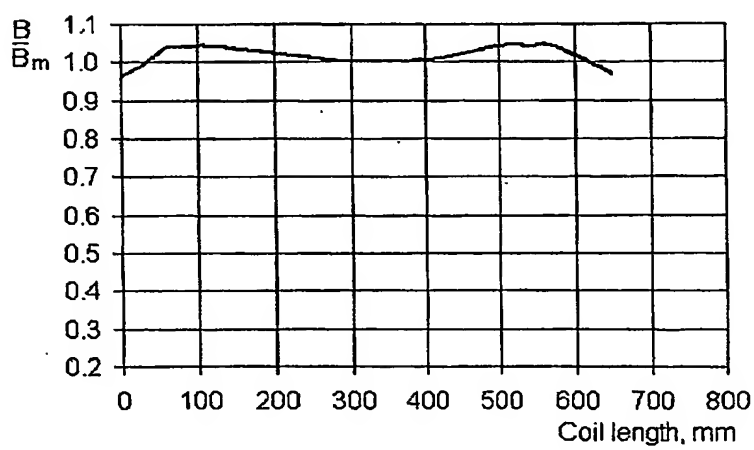
START
S100
Place sample in first coil
S110
Detect signals in first coil
S120
Move sample from first coil to second coil
Are there more samples?
No
Yes
S130
Place next sample in first coil
S140
Detect signals in first and second coils
S150
Remove sample from second coil
S160
Detect signals in second coil
S170
Remove sample from second coil
DONE

Fig. 3



B/Bm
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
100
200
300
400
500
600
700
800
Coil length, mm

Fig.6a



B/Bm
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
100
200
300
400
500
600
700
800
Coil length, mm

Fig.6b

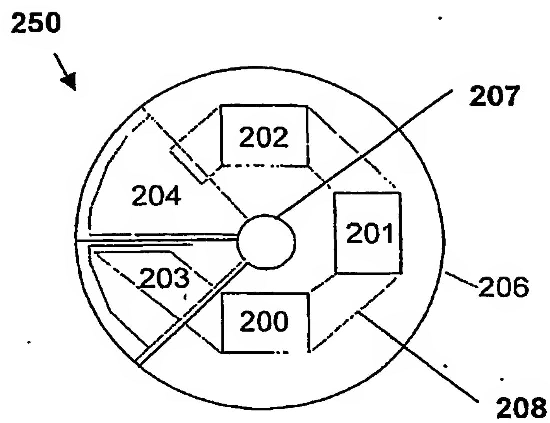

250
207
202
204
201
203
206
200
208

Fig 7

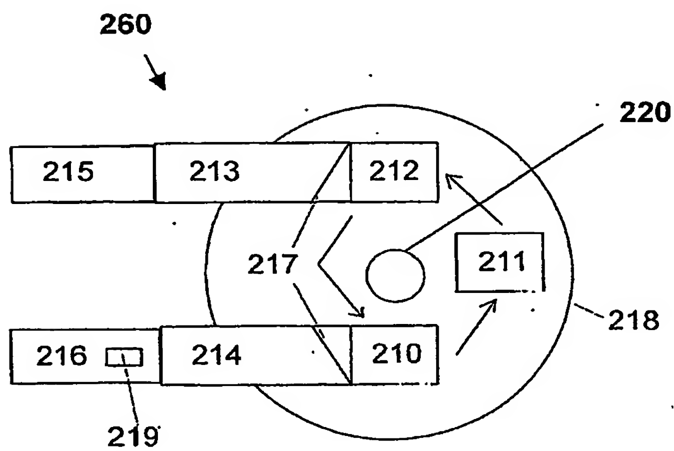

260
220
215
213
212
217
211
218
216
214
210
219

Fig 8

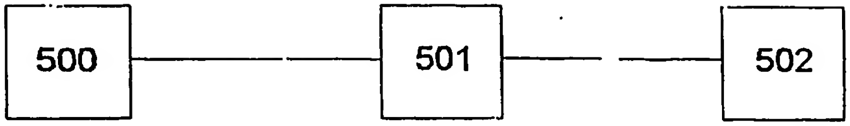


Figure 9

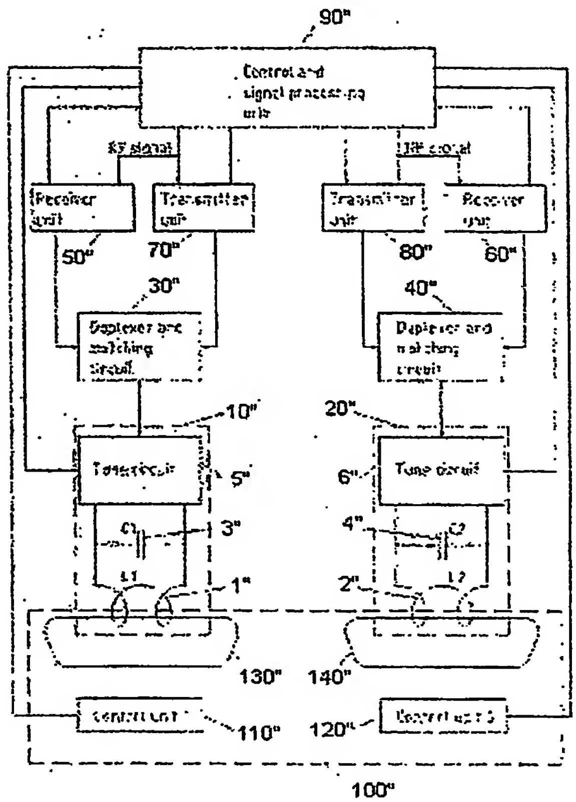


Figure 10